An optical transmission line and optical transmission system

Background of the Invention

Field of the Invention

The present invention relates to an optical transmission line that transmits signal light, and to an optical transmission system having the optical transmission line.

Related Background Arts

In an optical transmission system, it is desirable to lessen the absolute value of cumulative chromatic dispersion of the optical transmission line at a signal light wavelength in order to restrain the waveform degradation of the signal light. Also, in a Wavelength Division Multiplexing (WDM) transmission system, in which optical communication is performed by multiplexing signal light of plural wavelengths, it is desirable that the absolute value of cumulative chromatic dispersion of the optical transmission line be small in a wide wavelength range so that optical communication can be performed in a volume as large as possible by multiplexing the signal light as much as possible. Therefore, generally by connecting various kinds of optical fibers or by providing a dispersion compensation module to compensate for the dispersion of an optical fiber, the absolute value of the cumulative chromatic dispersion is made small in a wide wavelength range.

For example, in the technologies disclosed in Literature 1: M. Murakami, et al., "Long-haul 16x10 WDM Transmission Experiment Using Higher Order Fiber Dispersion Management Technique", ECOC'98, pp.313 - 314 (1998) as well as Literature 2: F. M. Madani, et al, "Performance Limit of Long-distance WDM Dispersion-managed Transmission System Using Higher Order Dispersion Compensation Fibers", IEEE Photon. Technol. Lett., Vol.11, No.5, pp. 608 - 610 (1999), the absolute value of cumulative chromatic dispersion is made small by connecting a standard 1.3 μm band zero dispersion optical fiber which has a zero dispersion wavelength near the 1310 nm wavelength, and in which both the chromatic dispersion and the dispersion slope are positive at the 1550 nm wavelength, with a dispersion compensating optical fiber in which both the chromatic dispersion and the dispersion slope are negative at the 1550 nm wavelength. The dispersion compensating optical fiber is, in some cases, installed in a relay section together with the 1.3 μm band zero dispersion optical fiber, and in other cases, it is rolled up in a coil as a dispersion compensation module to be put in a repeater or a receiver.

Literature 3: Y. Yokoyama, et al., "Practically Feasible Dispersion Flattened Fibers Produced by VAD Technique", ECOC'98, pp.131-132 (1998) discloses a positive dispersion optical fiber and a negative dispersion optical fiber: the former has a positive chromatic dispersion and a small absolute value of dispersion slope at the 1550 nm wavelength, whereas in the latter the chromatic dispersion is negative and the absolute value of the dispersion slope is small. When these two optical fibers are connected, the absolute value of

cumulative chromatic dispersion of the optical transmission line diminishes in a wide wavelength range.

As for the dispersion compensation that uses a dispersion compensation module, the installation and maintenance are easy. However, the transmission loss of the dispersion compensating optical fiber used in the dispersion compensation module is greater than that of other optical fibers. In addition the longer the length of the 1.3 μm band zero dispersion optical fiber, the longer the dispersion compensating optical fiber must be in the dispersion compensation module. Accordingly, the transmission loss of the optical transmission line becomes greater as a whole.

On the other hand, in a case where a 1.3 μm band zero dispersion optical fiber and a dispersion compensating optical fiber are coupled to be installed in a relay section, or in a case where a positive dispersion optical fiber and a negative dispersion optical fiber are coupled to be installed in a relay section, the loss in the whole optical transmission line becomes small as compared with in the where a dispersion compensation module is provided. However, different kinds of optical fibers must be connected within a cable; such connecting work and the maintenance are complex.

Summary of the Invention

It is an object of the present invention to provide an optical transmission line in which the absolute value of cumulative chromatic dispersion is small in a wide wavelength range and which exhibits a small loss and is easy to handle,

as well as an optical transmission system using such an optical transmission line.

In order to achieve this and other objects, an optical transmission line is provided which comprises (1) an optical transmission fiber having a chromatic dispersion of +4 to +10 $ps \cdot nm^{-1} \cdot km^{-1}$ and a dispersion slope of 0 to +0.04 $ps \cdot nm^{-2} \cdot km^{-1}$ at the 1550 nm wavelength and installed in a relay section, and (2) a module made of dispersion compensating optical fiber having a chromatic dispersion of -40 $ps \cdot nm^{-1} \cdot km^{-1}$ or less and a dispersion slope of -0.10 $ps \cdot nm^{-2} \cdot km^{-1}$ or less at the 1550 nm wavelength.

An optical transmission system is also provided in which a transmitter and a receiver are added to this transmission line.

In an embodiment of the present invention, the dispersion slope is +0.01 to +0.03 $ps \cdot nm^{-2} \cdot km^{-1}$, and the effective area is equal to or more than 45 μm^2. The chromatic dispersion is -80 $ps \cdot nm^{-1} \cdot km^{-1}$ or less, more preferably, -100 $ps \cdot nm^{-1} \cdot km^{-1}$ or less, and the dispersion slope is -0.20 $ps \cdot nm^{-2} \cdot km^{-1}$ or less.

The above and further objects and novel features of the invention will be more fully clarified from the following detailed description when the same is read in connection with the accompanying drawings. It is to be expressly understood, however, that the drawings are for the purpose of illustration only and are not intended as a definition of the limits of the invention.

Brief Description of the Drawing

In the drawings:

Figure 1 is a diagram showing the constitution of an optical transmission system and an optical transmission line according to an embodiment of the present invention.

Figure 2 is a graph showing an average chromatic dispersion of the optical transmission line in each of Implementation examples 1 and 2.

Figure 3 is a graph showing an average chromatic dispersion of the optical transmission line in each of Implementation examples 3 and 4.

Description of the Preferred Embodiments

In the following, preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. To facilitate the comprehension of the explanation, the same reference numerals denote the same parts, where possible, throughout the drawings, and a repeated explanation will be omitted. The dimensions in the drawings are partly exaggerated and do not always correspond to actual ratios of dimensions.

The optical transmission system 1 shown in Figure 1 is equipped, as an optical transmission line 2, with a repeater 31, an optical transmission fiber 41, and a repeater 32, at least in a part of the transmission path of signal light that extends from a transmitter 10 to a receiver 20. The repeater 31 comprises an optical amplifier 311, a dispersion compensating optical fiber 313, and an

optical amplifier 312. The repeater 32 has an optical amplifier 321, a dispersion compensating optical fiber 323, and an optical amplifier 322.

The transmitter 10 sends out signal light of plural wavelengths in the 1.55 μm wavelength band after multiplexing the wavelengths. The signal light propagates the optical transmission line 2 to the receiver 20. The receiver 20 receives the signal light, demultiplexing it to each wavelength.

The optical transmission fiber 41 exhibits a chromatic dispersion of +4 to +10 ps$\cdot$nm$^{-1}\cdot$km^{-1}, and a dispersion slope of 0 to +0.04 ps$\cdot$nm$^{-2}\cdot$km^{-1} at the 1550 nm wavelength. It is installed in the relay section from the repeater 31 to the repeater 32. Each of the dispersion compensating optical fibers 313, 323 has a chromatic dispersion of –40 ps$\cdot$nm$^{-1}\cdot$km^{-1} or less at the 1550 nm wavelength, and a dispersion slope of -0.10 ps$\cdot$nm$^{-2}\cdot$km^{-1} or less. It is rolled up in a coil as a module to be provided within the repeaters 31, 32. The optical transmission fiber 41 and the dispersion compensating optical fibers, 313, 323 are made of silica-based glass, and it is possible to design and produce a refractive index profile appropriately so as to give the above-mentioned characteristics of chromatic dispersion and dispersion slope, respectively.

Each of the optical amplifiers 311, 312, 321, and 322 amplifies the signal light of plural wavelengths altogether. An amplifier using an Er-doped optical fiber in which Er element is added to the light path region is preferable. The optical amplifier 311 is positioned in the first part of the dispersion compensating optical fiber 313 in the repeater 31, and the optical amplifier 312 is provided in the latter part of the dispersion compensating optical fiber 313.

In the same way, the optical amplifier 321 is positioned in the first part of the compensating optical fiber 323 in the repeater 32, and the optical amplifier 322 is provided in the latter part of the dispersion compensating optical fiber 323.

In the optical transmission system 1 and optical transmission line 2 thus constituted, at the 1550 nm wavelength, the sign of the chromatic dispersion of the optical transmission fiber 41 and that of each of the dispersion compensating optical fibers 313, 323 differ from each other. Also, the sign of the chromatic dispersion slope of optical transmission fiber 41 and that of each of the dispersion compensating optical fibers 313, 323 are different from each other. Consequently, the absolute value of cumulative chromatic dispersion of the optical transmission line 2 can be made small in a wide wavelength range by setting an appropriate ratio between the length of the optical transmission fiber 41 and each length of the dispersion compensating optical fibers 313, 323. Therefore, a broad bandwidth WDM transmission as well as a high bit rate transmission becomes possible. Also, in order to decrease the absolute value of the cumulative chromatic dispersion of the optical transmission line 2 in a wide wavelength range, it is preferable that the optical transmission fiber 41 exhibit a dispersion slope of +0.01 to +0.03 $ps \cdot nm^{-2} \cdot km^{-1}$ at the 1550 nm wavelength.

As compared with a standard 1.3 μm band zero dispersion optical fiber, the length of the dispersion compensating optical fibers 313, 323 that is necessary for compensating the chromatic dispersion and the dispersion slope can be short because the chromatic dispersion and the dispersion slope of the

optical transmission fiber 41 are small at the 1550 nm wavelength. Therefore, the loss of signal light in the dispersion compensating optical fibers 313, 323 is small. Accordingly, the loss of signal light in the optical transmission line 2 is also small as a whole.

In order to make the loss of signal light smaller by making the dispersion compensating optical fibers 313, 323 shorter, the dispersion compensating optical fibers 313, 323 preferably have a chromatic dispersion of -80 $ps \cdot nm^{-1} \cdot km^{-1}$ or less, and a dispersion slope of -0.20 $ps \cdot nm^{-2} \cdot km^{-1}$ or less at the 1550 nm wavelength, and more preferably, a chromatic dispersion of -100 $ps \cdot nm^{-1} \cdot km^{-1}$ or less at the 1550 nm wavelength.

Also, because to the loss of signal light in the optical transmission line 2 is small, the power of signal light which is emitted from each of the transmitter 10 and the repeaters 31, 32 is allowed to be small, and accordingly, the occurrence of the nonlinear optical phenomenon is restrained. Therefore, it is sufficient to provide only either one of the optical amplifiers 311 or 312 in the repeater 31, and either of the optical amplifiers 321 or 322 in the repeater 32. Incidentally, in order to restrain the occurrence of the nonlinear optical phenomenon more sufficiently, the optical transmission fiber 41 preferably has an effective area equal to or more than $45\,\mu m^2$ in the 1550 nm wavelength.

Moreover, the installation and the maintenance of this dispersion compensation module are easy because the dispersion compensating optical fibers 313, 323 are not laid but are rolled up in a coil as a module and are provided inside the repeaters 31, 32.

Next, the implementation examples of the optical transmission line 2 according to the present embodiment are explained in comparison with the comparative examples. In each of the implementation examples and the comparative example shown in Table I, the optical transmission fiber has a length of 80 km, and the dispersion compensating optical fiber has a length that is sufficient to compensate the chromatic dispersion of the optical transmission fiber at the 1550 nm wavelength. The optical transmission fiber of the comparative example is a 1.3 μm band zero dispersion optical fiber. Each characteristic is a value at 1550 nm.

Table I

Example #		Implementation examples 1	2	3	4	Comparative example
Optical transmission fiber	Chromatic dispersion $ps \cdot nm^{-1} \cdot km^{-1}$	5.7	5.7	5.7	5.7	17
	Dispersion slope $ps \cdot nm^{-2} \cdot km^{-1}$	0.024	0.019	0.024	0.019	0.056
	Effective area μm^2	47	61	47	61	-
Dispersion compensating fiber	Chromatic dispersion $ps \cdot nm^{-1} \cdot km^{-1}$	-110	-110	-52.8	-52.8	-110
	Dispersion slope $ps \cdot nm^{-2} \cdot km^{-1}$	-0.270	-0.270	-0.120	-0.120	-0.270
	Effective area μm^2	14	14	18	18	-
	Fiber length km	4.2	4.2	8.7	8.7	12.4
	Loss dB	2.6	2.6	2.8	2.8	7.6

The comparison between each implementation example and a comparative example is as follows. As for the length of the dispersion compensating optical fibers, the comparative example is 12.4 km, whereas that of each implementation examples 1 and 2 is 4.2 km, and implementation examples 3 and 4 is 8.7 km, respectively; thus, each implementation example is shorter than the comparative example. As to the loss of signal light in the dispersion compensating optical fibers, the comparative example is 7.6 dB, whereas that of each implementation examples 1 and 2 is 2.6 dB, and that of each implementation examples 3 and 4 is 2.8 dB; thus, each implementation example is smaller than the comparative example by about 5 dB. Therefore, in each implementation example, the S/N ratio improves by about 5 dB as compared with the comparative example. Also, it is possible to restrain the occurrence of the nonlinear optical phenomenon by decreasing the power of signal light because the deterioration of the S/N ratio of signal light in the dispersion compensating optical fiber is small.

A comparison between implementation examples 1 and 2, and implementation examples 3 and 4, show that as to the length of the dispersion compensating optical fiber the former is 4.2 km, and the latter is 8.7 km, whereas they are almost the same with respect to the loss of signal light in the dispersion compensating optical fibers. This is because the latter is smaller than the former with respect to the transmission loss of the dispersion compensating optical fibers per unit length.

As shown in Figures 2 and 3, the average chromatic dispersion of the whole optical transmission line in which an optical transmission fiber and a dispersion compensating optical fiber are connected is zero at the 1550 nm wavelength in each implementation example. Also, the average dispersion slope of the whole optical transmission line in which an optical transmission fiber and a dispersion compensating optical fiber are connected is small at the 1550 nm wavelength in each implementation example. Consequently, the absolute value of cumulative chromatic dispersion of the optical transmission line is small in a broad bandwidth in each implementation example, and broad bandwidth WDM transmission and high bit rate transmission are possible.